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TRANSACTIONS.

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No. 771.

A HIGH-SPEED GRAVITY FILTER BED.

By A. McL. Hawks, Jun. Am. Soc. C. E.

Presented September 4th, 1895.

WITH DISCUSSION.

The following description of a filter bed designed and constructed for the Tacoma Light and Water Company by the author, as engineer in charge, may prove interesting because of the rapidity of construction, extremely low first cost, ease and cheapness of operation, and the excessively high speed at which it was operated. On May 12th, 1892, the author was consulted by the chief engineer of the Tacoma Light and Water Company concerning the necessity of purifying that portion of the water supplied to the city of Tacoma which comes from brooks situated about 10 miles south of the city upon the gravel prairie, and the means to be used to obtain such purification.

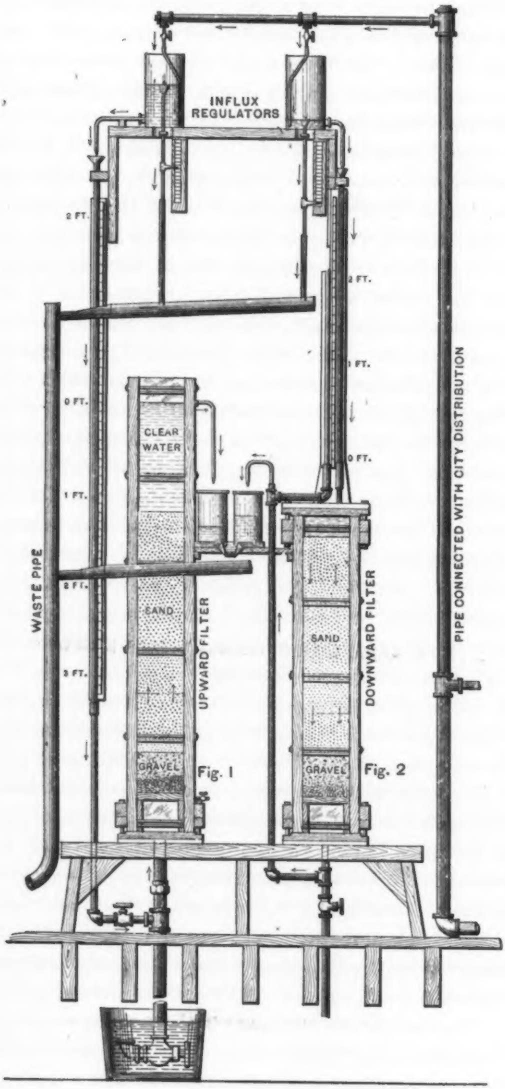
In order to understand the demand for such a move on the company's part, it will be necessary to explain the causes and surroundings. Bushalier Creek, from which the company took its upper supply, is the outflow from a small lake called Spanaway, which has a surface area of 260 acres, and is supplied from springs in and about the lake

and from one main feeder 5 miles long. The normal flow of Bushalier Creek is from 5 000 000 to 7 000 000 galls. in the dry season, rising to 20 000 000 or 25 000 000 galls. in the rainy season. On the banks of the lake are several farms and a town, Lake Park, with 500 inhabitants, and the whole length of the feeder is through farms and tilled land. Although the houses stand upon a gravel plain 10 to 50 ft. above the lake level, which would act as a rough filter of that depth, contamination steadily increased until the spring water from the gravel beds had become very offensive in the dry season; added to this was the growth of algæ and other low forms of animal and vegetable life which thrive wonderfully on the Pacific Coast, and when dead and decaying give a particularly rank odor and taste to the water.

At the time the author was called upon, these causes had not operated sufficiently long to demand a very elaborate or costly plant; and, too, the company had already purchased Maplewood Springs, having a minimum flow of 11 000 000 galls., and proposed to purchase others, so that ultimately the whole supply would come from pure sources beyond possible contamination. The whole matter was therefore regarded as a temporary expedient to last but a few years and to be used only during the summer months, and economy of construction and operation, as well as that bane of all engineers' lives, great haste for completion, were a desideratum.

Mechanical filters were considered, but the time required to negotiate for such a plant, as well as the first cost, debarred them; the Anderson process was seriously considered, but cost also barred this. To grade and prepare the requisite space in which to operate a gravity filter at 50 galls. per square foot upon the system in use at Lawrence, Mass., would cost $2 200, and for roofing over such an area, an absolute necessity in this climate, the cost would be $3 000. These two items were sufficient to put this out of the question. There remained practically but one thing to do, and that was to design a new form of bed which could be operated at a much higher speed than usual.

While a student in the office of J. Herbert Shedd, M. Am. Soc. C. E., the author studied the "Report on the Filtration of River Waters," by the late J. P. Kirkwood, Past President Am. Soc. C. E., and in leisure hours made many experiments, using as his original plant some very large flower-pots, graduating later on to two lengths of 8-in. drain tile. At a still later date, while employed in the office of the water-


INFLUX REGULATORS
2 FT.
2 FT.
1 FT.
0 FT.
0 FT.
CLEAR WATER
1 FT.
2 FT.
3 FT.
WASTE PIPE
SAND
UPWARD FILTER
GRAVEL
Fig. 1
SAND
DOWNWARD FILTER
GRAVEL
Fig. 2
PIPE CONNECTED WITH CITY DISTRIBUTION

works commissioner of the city of St. Louis, the experimental filters then being run furnished much valuable information. The two small filters, Figs. 1 and 2, had sides made of plate glass, thus showing plainly every action which took place within them. They were run at the regular rate of 50 galls. per square foot per day.

It was noticed in their operation that a head of 0.1 ft. was sufficient to run them for some time; as they clogged, this head increased to 3 ft. for the downward type, and 1 ft. for the upward. When this point was reached, they were cleaned by removing the top layer of sand in the former and reversing the flow in the latter, after which they would be started again with the same head as at first. If much greater head was put upon them a break would occur, forcing the sand down into the gravel in the downward type, or, passing up in the other, would agitate the sand in the manner which is seen in every boiling spring, in both cases destroying the integrity of the filter and distributing the impurities all through the sand. Other minor puzzling questions were solved by the glass filters, but this was the most important, as it explained why no more than about 100 galls. per square foot could be forced through the tiles without seriously affecting their filtering qualities. These glass filters suggested one important question: If a head of 3 ft. could be safely imposed on them without injury, simply because a thin coating of impurities acted as a damper to retard the flow and reduce the pressure, thus preventing disturbance of the sand, why could not some means be devised to hold the sand in place and make use of a part of that head for operation, running them at a much higher speed? Accordingly it was decided to attempt in these beds to run at a speed of 500 galls. per square foot per day. To do this work required a sand of large grain, free from all finer matter, and there was the danger that the chief usefulness of a filter, viz., its ability to thoroughly strain out all impurities might be lost. To avoid this and to help hasten the process, it was determined to use a coagulant. Three of the cheapest and readiest were considered: alum, borax and iron in the form of oxide or carbide. The first two are comparatively expensive and are open to the further objection that they add a certain hardness to the water and are considered unhealthy by many. The third is very cheap and lasting; and if a small quantity enters the filtered water it only acts as the rusty nails which it was formerly thought necessary to keep in the water-pail to have the very best water.

It was decided also to have some form of aeration in connection with the filters. Much has been written on both sides of the case concerning the value of entrained air as a factor in the purification of water. In intermittent filtration, where the periods of submergence are short and at infrequent intervals, it is doubtless one of the greatest factors; but in filters which are in constant use, where the exposure to the air is only for an hour or two every few days, or possibly weeks, not much can be expected from this cause. As a matter of fact, the glass filters at St. Louis showed no sign of holding entrained air at any time; and as will be shown later on, the Tacoma filters showed no sign of its presence 15 minutes after the water was turned on. That oxygen is one of the best purifying agents known, no one will deny; that such a small amount as could be retained and not be found in a filter so exposed as this was could be of value may be doubted. In order that air may act beneficially either the water must be thoroughly exposed to it in the form of thin sheets falling over weirs, or else the air must be introduced and thoroughly mixed with the water in the form of minute bubbles. As this latter method required the installation of some form of air compressor, it was passed over and the first was used.

With the foregoing premises in mind it was determined to construct a filter having these main features, viz., screens at the headgate to remove all large trash; a flume of sufficient dimensions to give at least 10 minutes' time to operate on the water while it was in transit; grade to make five overfalls, and as many slopes to agitate the water; five level sections to hold scrap iron and punchings; and, finally, an upward filter in which to remove all impurities; to be roofed over, and to operate at the rate of 500 galls. per square foot per day.

On May 14th the author made a rough survey of the locality where the filter was to be built and immediately commenced the plans. "Rapidity of erection and economy of construction and operation" were the instructions most constantly urged, and too often were made the limit to which all arguments were brought, to the detriment of the operation of the filters. Good work was done by them; better could have been, had this motto not been brought forward so frequently and had a little more money been expended in filling out the plant and making it in strict accordance with the best ideas.

An old saw-mill acquired by the company when they purchased the water right was used as a shed in which to install the beds. The old

flume leading to town passed a few feet to one side of this, the creek about the same distance on the other. The old diverting dam at the head of the flume was 430 ft. distant from the mill and at such an elevation that by adding about 3 ft. to its height and excavating to the mud-sills of the old mill, the flume could be built to the desired grade, with the overfalls as planned. All these things combined to make a very economical construction. The cut to be made for the flume was entirely through gravel, which furnished most of that material required in the filter save the smallest size. Sand of a suitable quality was not to be had at a nearer point than a pit 3 miles distant, which made the price laid down at the mill $1.25. When this sand was thoroughly washed and screened it made but ⅔ cu. yd., so that the price could really be called $1.80, inclusive of labor in washing.

On May 17th plans were completed and the bill of material given to a neighboring mill to be filled. The next day men were put on the ground and the actual work of construction commenced. The total bill for the tools, exclusive of those used by the carpenters, was about $100, of which about $50 was credited to the work upon completion. The cost of different portions of the work was segregated for use in future work of similar character. Laborers were paid $2 per day and carpenters $2.75 to $3.50; teams cost $4 where used on the work, though most of the teaming was on small contracts.

The diverting dam required 6 000 ft., B. M., of timber, worth $72 in place, and 200 cu. yds. of earth and gravel at 20 cents per yard; part of the face was paved at a cost of $15.

The headgate called for 500 ft. of lumber worth $15 in place, and it cost $10 to excavate and backfill the site. The screens cost $5. The flume cost 40 cents per linear foot for lumber and erection, or $172; the excavation and filling along the whole 430 ft. cost $275. The scrap iron weighed 8 500 lbs. and cost $65. The cost of clearing out the gravel and refuse in the old mill was $75, and the repairs and alterations $125. The cost of lumber in place to construct the beds and house flume was $180. The gravel for the filters cost 35 cents per cubic yard washed and in place in the beds. After 45 cu. yds. of sand had been hauled from the pit to the filters, a deposit was found near the headgate. Although all material taken from this latter pit had to be replaced by gravel from the cut, because it was so near the headgate and the edge of the pond, it cost less to excavate, screen, wheel into the head

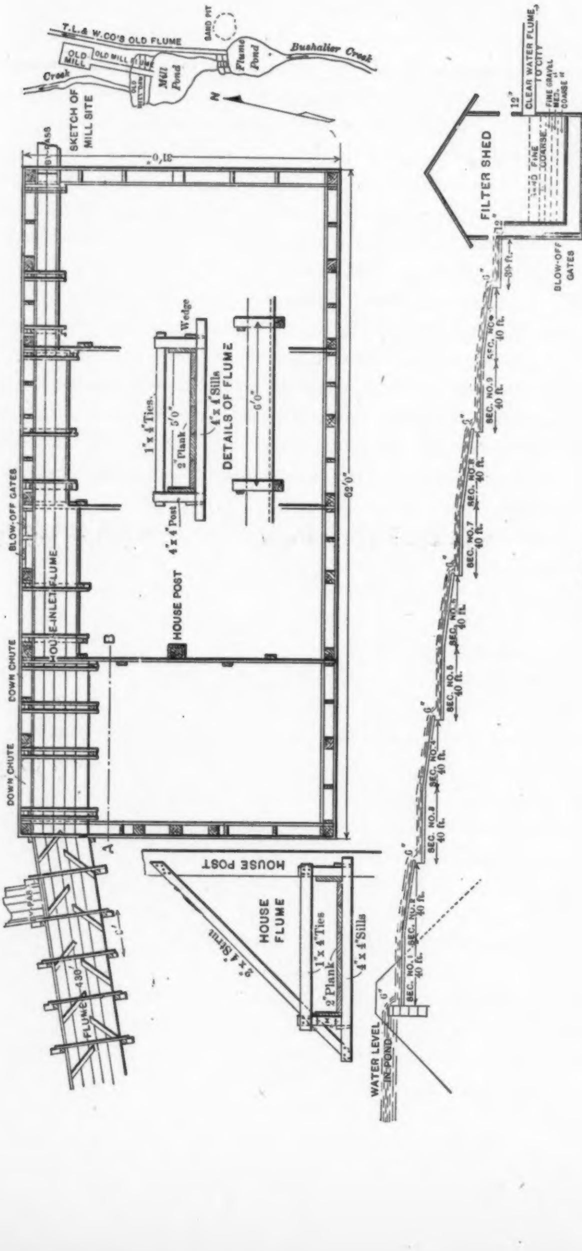

T.L.& W.CO'S OLD FLUME
SAND PIT
OLD MILL
OLD MILL FLUME
Creek
Mill Pond
Flume Pond
Bushalier Creek
N
SKETCH OF MILL SITE
BY-PASS
31'0"
62'0"
BLOW-OFF GATES
HOUSE-INLET FLUME
DOWN CHUTE
DOWN CHUTE
HOUSE POST
1"x 4"Ties.
2"Plank
4"x 4"Sills
4"x 4"Post
Wedge
5'0"
6'0"
DETAILS OF FLUME
A
B
HOUSE POST
HOUSE FLUME
2"x 4"Strut
FLUME 430'
FILTER SHED
CLEAR WATER FLUME TO CITY
FINE GRAVEL
SAND FINE
COARSE
BLOW-OFF GATES
WATER LEVEL IN POND
SEC. NO. 1 40 ft.
SEC. NO. 2 40 ft.
SEC. NO. 3 40 ft.
SEC. NO. 4 40 ft.
SEC. NO. 5 40 ft.
SEC. NO. 7 40 ft.
SEC. NO. 8 40 ft.
SEC. NO. 9 40 ft.

FIG. 3.

of flume, wash down to the filter and put in place than to prepare the first lot. One reason for this was that the water in the flume both washed and transported it to the house; two men on this part of the work handled over 20 cu. yds. of cleaned sand a day after some "sand hustlers" were made for them. These were simply boards with handles nailed to them, so the men could walk alongside the flume and direct the current of the water as they pleased by partially damming the stream with the "hustlers." The dirt and finest sand would travel most quickly and be wasted out into the creek at a by-pass above the house; then the main part of the sand would follow, flowing into the house as the water was drawn off through the by-pass at the lower end of the house. In this way thoroughly washed sand was delivered to such a point that it could be cast into place at one handling.

Beside the ordinary repairs and alterations it was decided to make a considerable part of the sides of the mill in the form of a blind lattice in order that air might have free access and yet sunlight and falling leaves be excluded and danger from outside interference be lessened. This cost $65.

Repairs costing $50, necessitated by the construction of this filter, were made to the old flume and headgate.

The total cost of the filter bed was as follows:

Tools and implements	$50 00
Clearing at dam	25 00
Constructing dam	127 00
" headgate	30 00
" flume	447 00
Repairs and alteration of old mill	200 00
Carpentry of beds and house flume	180 00
100 cu. yds. gravel	35 00
30 cu. yds. sand	54 00
140 cu. yds. sand	140 00
Latticing mill and old flume repairs	115 00
Total	$1 403 00

This may be safely taken as "economy of construction."

The work was completed on June 29th, or in 37 working days from the day men were first put on the ground, which certainly filled the requirement of "rapidity of execution." The construction of the plant is shown in Figs. 3 and 4. Water was turned through the beds at once and allowed to run until no sign of turbidity was visible. The headgate was then closed while the iron was being stacked in the level sections of the flume and the diagonal strips in the slopes. Before the iron was placed it was washed and roasted, to remove any dirt or machine oil which the turnings and punchings had retained. The stacking was in the shape of windrows across the flume every 5 ft., leaving a space at the head and end of every level section. Water was then turned on, the filters filled and blown off once more

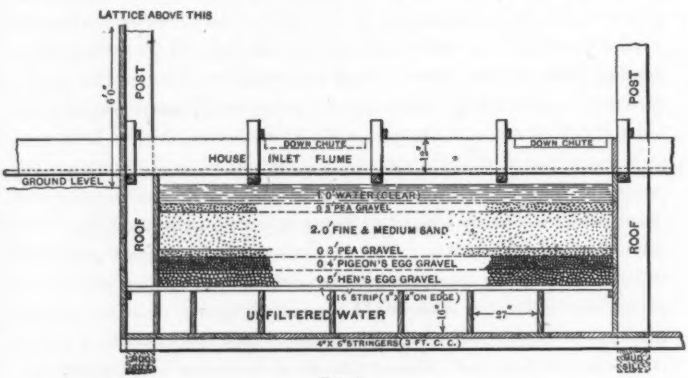


FIG. 4.

and then put into actual operation. This process of cleaning an upward filter by blowing off was very simple and was done easily. The gate at the head of the house flume was closed, that of the by-pass adjacent being opened at the same time, and the water wasted into the creek; the blow-off gates at the side were opened wide, allowing the water to flow quickly out from beneath the sand, and that from above to reverse its direction of flow, and, pushing back, to wash the impurities from the lower face of the sand. The blow-off was then closed, the house gate opened, the by-pass closed, and water once more admitted to the filter. The time required to empty the filter was 5 minutes, so the speed of the descending current was more than 10 times its usual up-

ward flow, which should be current sufficient to remove any particles held against the face of the sand. Water was admitted as rapidly as the flume would permit until the "tell-tale" showed it had risen to the pea gravel beneath the sand; then it was reduced to its normal flow, and in 40 minutes after the gates were opened the filter was in full operation.

For several weeks much of the author's time was devoted to operating these beds, and great care was taken to maintain them at their best. While they were being constructed causes had arisen to compel the speed of operation to be raised to over 700 galls., and times were frequent when 1 000 galls. were passed successfully without disturbing the materials or destroying the integrity of the plant.

The first change to be made was in the removal of the turnings of steel from the iron, on account of the tendency of the rows to rust into a solid mass and so cause the water to run over the top instead of passing through the rows. Next came the removal of the punchings from a like cause, and finally all scrap was thrown out and old horse shoes substituted throughout. These last made the best rows, were more easily handled and more satisfactory in every way. The matter of handling became of some moment, as it was necessary to change the rows every second or third day after operations had been carried on for a few weeks. The iron seemed to be a great attraction to all sorts of living creatures in the water, and in two days after being placed in the flume a shoe would be covered with insects to such an extent as to impair its usefulness seriously. New rows were then placed beside the old ones, the latter removed to a drying heap, where they lay in the open for a day, and then a big fire of brush made about them and they were roasted. More than a bushel of remains was gathered at the drying place in one month. This was one of the unexpected features of the work and one the author has never seen mentioned elsewhere. It was supposed when work commenced that renewal of the iron every month would be sufficient, in fact no extra supply had been prepared to replace the first lot, which was an economy, as later events proved; for in all likelihood, such an extra quantity would have been in the shape of turnings, punchings and scrap, which would have been useless.

The next trouble came from the screens at the headgate, which were made from such copper wire screen stuff as could be purchased

in town. For a little time this did fairly well, but as soon as the temperature of the water in the lake began to rise, the algæ began to grow and float down stream, and becoming entangled in the screens, were very difficult to remove; in efforts made to remove them the screens would become badly misshapen and require renewal. As the author had used perforated copper and brass plates in Colorado under similar circumstances he purchased some from the Harrington and King Perforating Company of Chicago, at a cost of $44, which served the purpose perfectly and soon saved the seemingly large first cost in the time and labor formerly expended in cleaning, beside all cost of renewal, as these were never worn out or broken. Probably nine-tenths of the time and energy formerly expended upon the screens was saved, and as they were cleaned five to seven times a day this meant considerable to the man in charge.

In blowing off these filters, of course most of the water drops out of the sand and its place is at least partly occupied with air, which is drawn into the partial vacuum in the sand bed. This is the case much more than with any downward filter, especially when this latter in time of cleaning has the water drawn down only a little below the surface of the sand, to remove the top layer. When the beds were refilled a good opportunity was given to watch the effect of the entrained air; as the water reached the surface the greater part seemed to rise with it; for 5 minutes quite an ebullition went on; gradually this ceased until at 10 minutes it had practically stopped; and at the end of 30 minutes no sign could be found in the beds of its having been present. This seemed to refute the idea that entrained air was of any practical value in this type of filter.

The iron acted rather slowly as a coagulant, and the water was not as thoroughly aerated as was desirable; but the combination of these two was thorough if only sufficient time was given. Samples of the water taken as it was discharged from the house flume showed the presence of the iron in a faint milky tinge; samples which were well shaken rapidly increased in this, and some bottles which have been kept more than two years show the bottom third as if filled with liquid opals, but the water has no smell or taste, nor has it at any time undergone anything like fermentation.

After running this plant for some weeks, during all which time it was operated at a higher speed than designed for, the company decided

to erect the second plant upon similar plans at Clover Creek, and a care-taker was put in charge. So the management fell into other hands and for some months the author had neither time nor opportunity to observe its further workings. After that the water and electric light plants were sold to the city; and at the same time a farmer lower down on the creek took out an injunction to prevent the operation of blowing off the filters, as it destroyed the purity of the stream where it flowed over his land. So the plant has not been operated for some months, and there seems to be no likelihood of its ever being used again to continue these investigations.

From what was seen of the operation of this plant, the author was led to believe that a most successful plant could be built by observing the following rules, viz., to have the screens at the headgate so arranged as to remove all large matter; to thoroughly aerate the water before it reaches the iron as well as afterwards, as in that case the oxide is more freely given off by the iron and absorbed by the water; to so place the iron that the water is compelled to come into thorough contact with it, and that it be agitated in the water, as well as be capable of ready removal and replacement; to give sufficient time for the air and iron to act upon the water before subjecting it to filtration; and finally, in the filter itself, the sand should be most carefully graded and the changes from pea gravel to the finest sand be made carefully and evenly. Every detail of construction and all materials should be rigidly inspected, and every item should be watched carefully in operation.

With these points thoroughly worked out, a filter operating at the rate of 500 galls. should be a commercial success as well as a mechanical one. The first cost of the beds depends greatly upon the structure of the house in which they are installed; for the beds alone $1 50 per square foot should be ample; for roofing the same, 35 to 50 cents; for flume with weirs, iron, etc., $1 per linear foot should be estimated; if aeration by jet of air be used the cost of such a plant must be added. In operating, the services of one man on each shift should be sufficient for a 5 000 000-gall. plant, provided the iron can be changed readily; for such work the man must have some idea of mechanics, and would be well worth $75 per month. The cost of raising the water, say 5 ft., for overfalls, or of running a small air compresser, would not be more than $2 per day.

The total cost of constructing a 5 000 000-gall. plant would be about as follows, allowing 10% excess for cleaning purposes :

Excavating site, 11 000 sq. ft., 7 ft. deep, about 3 000 cu. yds., at 20 cents	$600 00
Concrete floor of same, 400 cu. yds, concrete at $5	2 050 00
Rubble masonry walls—	
420 ft. outside walls, at $10	4 200 00
560-ft. division walls, at $8	4 480 00
Flume for intake, 800 lin. ft., at $1	800 00
Filter beds, 11 000 sq. ft., at $1 50	16 500 00
Roofing for same, at 50 cents	5 500 00
Blow-off gates, pipes, etc	2 500 00
Total	$36 630 00
Add for contingencies	3 663 00
" " engineering and superintendence	2 500 00
Total	$42 793 00

The cost of operation would be—

Two men, at $75 per month	150 00
Cost of pumping, extra 5 ft. elevation	60 00
	$210 00

This makes the cost per 1 000 000 galls. (150 000 000 galls. per month), $1.40. To this must be added interest on the investment, and a small amount for renewals, everything being contemplated to be of the most durable character.

DISCUSSION.

Mr. Hering.

RUDOLPH HERING, M. Am. Soc. C. E.—About six months after the filter described in the paper had been put in operation, the speaker make an examination of it. The applied water was objectionable mainly on account of the very large number of infusoria it contained and not on account of any sewage pollution. The wash water from the filter, after the current was reversed for cleaning the beds, contained myriads of various varieties of small organisms. No such life was detected in the filtered water. It was practically all removed during the passage of the water through the fine sand. The filter acted principally as a strainer to remove such organisms. Apparently the iron did not have much effect on the results, although it produced a little coagulant. Owing to the fact that no chemical or bacterial analyses had been made to determine what the filter actually accomplished, the speaker considered it impossible to judge of its value other than as a strainer, in which role it was successful.

In the correspondence (see page 59) on the paper, Mr. Hill implied that typhoid fever deaths are due wholly to water supplies, to which statement the speaker took exception. At Atlanta, Ga., to which city Mr. Hill makes a direct reference, the speaker believed that the typhoid fever death rate cannot be due wholly, if at all, to the water supply. The former supply was drawn from a small area on which there was a very small population, and the entire territory was kept under very strict supervision by the local board of health. The new supply is drawn from a large stream, the Chattahoochie River. There is a small population above the point where the water is taken. The river water is very turbid, containing much clayey matter in suspension, and it is there fore doubtful if any typhoid fever germs could survive after the water has been treated by the thorough filtration process, which leaves it very clear. It is definitely known that typhoid fever is not only propagated through public water supplies, but also in other ways. Milk has been shown to spread the disease, and there are still other ways in which it is done; therefore the speaker did not regard the specific arguments advanced by Mr. Hill on the typhoid fever death rate based only on the water supplies as very sound.

CORRESPONDENCE.

S. Bent Russell, M. Am. Soc. C. E.—The author states that the filter was only some weeks in operation. Judging from some years' experience with experimental filters, the writer would consider this time of some weeks altogether too short to show the practical working capacity of such a filter as the one described. Mr. Russell.

On examining the records of the experiments with the St. Louis filter described in the paper, it will be found that while the new filter started with a very low head, after some 20 reversals had been made, it took a foot of head to start it after cleaning. Again the head of starting after reversal increased steadily, and at the end of from 6 to 12 months the entire filtering material had to be removed. This showed that reversals of flow did not thoroughly clean the sand. Had the filter been run at the rate of 500 galls. per square foot per day instead of 50 galls., it would probably have been hopelessly clogged inside of a month. That is to say it would have been past relief from reversal of flow. Furthermore, if the sand in the Tacoma filter were not thoroughly cleaned by reversal, the oxide of iron used as a coagulant would have a strong tendency to cement the sand together so that it could not be used again, judging from the way the iron trimmings and punchings behaved.

The development of the American mechanical filter on the lines that it has followed indicates pretty plainly that filter sand cannot be cleaned properly by a simple flow of water through the interstices. The sand must be disturbed either by a rake of some kind, or by jets, or by a current strong enough to upheave and agitate the sand.

Returning to the coagulant used, the author's words would convey some doubt as to its success with a high rate of filtration. In his estimates he allows nothing for the scrap iron used. If enough iron were used to have much effect on the water the cost of it would be a considerable item, judging from the proportion of iron consumed in the Anderson process. Of course much would depend upon the quality of the water when it reached the filter, and there seems to be nothing very definite on that point in the paper.

To sum up the foregoing, in the judgment of the writer, the Tacoma filter would not prove a success in the purification of water containing much solid matter.

It is apparent on reading the paper that the author has experienced some of the difficulties that beset the path of the engineer who invades the labyrinth of the filter problem. He has displayed unusual courage in giving whatever data or lack of data he has obtained in his experience. The literature pertaining to mechanical filtration is most meager

Mr. Russell. indeed. This is remarkable when the sums of money now invested in mechanical filters in the United States are considered. Do the parties now making and using such filters wish to suppress the truth or are they ignorant of what the filters really are doing? It seems impossible to obtain authoritative and reliable data as to what a modern filter will do. Perhaps the main difficulty lies in the fact that the subject is much too intricate for the capacity of the ordinary manufacturer or water-works superintendent. If this be all, the large manufacturers should advance the necessary funds, and employ one or more engineers of standing to make efficient tests of filter plants now in operation and report the same for publication.

In view of the slighting treatment shown the mechanical filter by Mr. Allen Hazen in his new book on filtration, and in view of some recent reports by engineers favoring the European system, something of the sort ought to be done. The makers of filters should either prove their claims or cease to advance them. To be of value the tests would have to be made according to scientific rule, so that the results should be at least as definite as in the case of an engine or boiler trial.

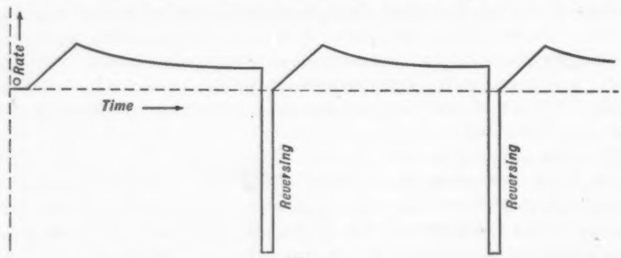


FIG. 5.

The writer for the last few years has had charge of some rather painstaking experiments on the purification of river water, and has at least learned something about the difficulties in the way of a scientific study of water filters. The primary factors in such an investigation are the water, the impurities or solids to be removed, the sand, the coagulant (if used), and time. As each factor is variable, the number of possible combinations approaches the infinite. No simple formula or curve diagram can be expected to represent the true relations of the factors. Take the case where the impurities, sand and coagulant are constant in their effect in a mechanical filter operated in the usual way and so as to give the maximum flow of filtered water. The filter must be started slowly or the filtrate will not be clear. Gradually the head and rate are increased until the maximum allowed head is reached; the maximum rate of filtration is also reached then. The head may now remain constant, while the rate will gradually decrease as the sand becomes clogged until the time for reversal comes around.

The rate of filtration may now be said to become negative, if clear water is used for washing. When the sand is clear another cycle is begun. Mr. Russell.

If a profile of the rate of filtration as it changes from hour to hour is plotted, it will have a form somewhat like Fig. 5. To get the capacity of the filter per day the average straight line must be found. The form of the diagram will change with the depth and ~~firm~~ness of fine the sand, with the proportion of coagulant used, with the purity of the water, and probably with the temperature of the water.

To obtain comparable results some means of recording the quality of the water and the quality of the sand must be adapted, and thanks to recent experiments this can be done with reasonable success. It is to be hoped that future experimenters will make some effort toward uniformity of methods. Until something better appears, all filter sand should be analyzed by the method described by Mr. Hazen.

EDMUND B. WESTON, M. Am. Soc. C. E.—As the thorough purification of water at the present time may be considered a science and in order to form an intelligent opinion of different methods of water purification, it is eminently essential that reliable results which have been obtained by different processes should be given for comparison. It would, in the opinion of the writer, be a valuable addition to the information contained in the paper if the author would give the following data: (1) The percentage of the number of bacteria contained in the applied water that was removed by the process he mentions. (2) The percentage of albuminoid ammonia removed. (3) The percentage of ready-formed ammonia removed. (4) The percentage of color removed. (5) The percentage of the total amount of water filtered during a run that it was necessary to use in order to wash the filtering medium. (6) The percentage of the total amount of water filtered during a run that it was necessary to waste, after washing the filtering medium, before the filtered water arrived at its normal condition. Mr. Weston.

The following results, which are germane to the subject, are the average results derived from experiments which were conducted under the special direction of the writer in 1893 and 1894, at Providence, R. I., with an experimental gravity mechanical filter 30 ins. in diameter:

Water bacteria removed	98.6%
Applied *Bacillus prodigiosus* removed	99.8%
Albuminoid ammonia removed	70.0%
Ready-formed ammonia removed	91.0%
Color removed	72.0%
Percentage of the total amount of water filtered during a run necessary to wash the filter bed.	4.9
Percentage of the total amount of water filtered during a run necessary to waste after starting the filter.	2.9

About nine months were devoted to making the experiments, which included the warmest and coldest seasons of the year.

Mr. Weston. Basic sulphate of alumina was added to the applied water at an average rate of 0.6 grain per gallon of applied water. The average rate of filtration was 128 000 000 galls. per acre per 24 hours, or about 2 938 galls. per square foot per 24 hours. The average length of run of the experimental mechanical filter was 16.7 hours for a rise in height of 4 ft. of water after the filter commenced to discharge at an average rate of 128 000 000 galls. per acre per 24 hours.

The average results obtained from the many runs of the experimental filter covered a period during each run commencing from 20 to 30 minutes after the filter was started to the end of the run. The filtered water did not reach its normal condition until at the expiration of the 20 to 30 minutes mentioned, and was therefore allowed to run to waste.

Great pains were taken in order to ascertain if any of the applied basic sulphate of alumina came through the filter in the filtered water, and the writer is of the opinion that it was satisfactorily demonstrated that none passed through the filter in its original state, although a minute quantity of finely suspended aluminic hydrate could be detected in the effluent water by the application of the logwood test.

Mr. Hill. JOHN W. HILL, M. Am. Soc. C. E.—Apart from the statement that the filter was operated at rates of 500 to 1 000 galls. per day per square foot, no information is given of its efficiency. The true test of a filter, in the light of the present knowledge of such matters, is the removal of bacteria, and any filter which will satisfy this requirement will probably satisfy all others. If any sanitary advantages were obtained from the filtration of water by the method described in the paper, it is to be regretted that these were not recorded with the same care as to detail which the author gives to the items of cost.

Certainly the cost of construction when the capacity of the filter is considered was very low, and the cost of operating a plant with a capacity of 5 000 000 galls. per day is also very low, but if this cost is attended only with an incomplete clarification of the water, and the removal of some of the comparatively coarse algæ, which might be done with a much simpler apparatus, it is doubtful if even this small cost of $1 40 per 1 000 000 galls. of water treated is justified. The writer has contended* that a partial purification of water by these high-speed and some of the low-speed filters is more dangerous from a sanitary standpoint than no attempt at all at purification, because the consumer, after the water passes any filter, takes its wholesomeness for granted, while in many cases on record no improvement at all has been made in the potability of the water, although all objectionable color and odor may have been eliminated from it.

Gauging the efficiency of filters by the typhoid fever death rates of the cities supplied, the most successful results have been obtained

* See the *Transactions* of the American Society of Civil Engineers, Vol. XXXII, p. 130.

from the fine sand filters in Holland, and these are operated at low rates per square foot of filter area. The effect of careful filtration of the Elbe water for Hamburg, under the direction of an expert like Dr. Dunbar, is well shown in a comparison of the typhoid fever death rates of this city for the years 1892 and 1894, during the former of which the raw river water alone was used, with a death rate of 34 per 100 000 of population, while during the latter year filtered water alone was used, with a typhoid death rate of six per 100 000 population, or the reduction of typhoid fatalities was nearly 82 per cent. Mr. Hill.

From a compilation of statistics upon which the writer is now engaged, some facts with reference to the practical results of mechanical filtration will be of interest in this connection. Of three American cities using water from mechanical filters, the following statistics are given:

Death Rate from Typhoid Fever per 100 000 of Population.

	1890.	1891.	1892.	1893.	1894.	Average.
Davenport, Ia.	19	11	35	17	26	21.5
Knoxville, Tenn.	101	45	37	67	59	62
Atlanta, Ga.	149	119	87	66	43	93

Now take several cities abroad using fine sand filters, with low rates of filtration per square foot of filter area, for the same years:

	1890.	1891.	1892.	1893.	1894.	Average.
The Hague	3	12	4	2	3.4	5
Berlin	9	10	8	9	4	8
London	16	15	11	16	15	15

Of all cities in the United States using mechanical filters, from which the writer has been able to obtain the vital statistics, Davenport, Ia., shows the lowest typhoid fever rate, but even this city for the past five years has had an average rate four times that of The Hague, two and one-half times that of Berlin, and 40% greater than that of densely populated London, where 83% of the water supply is obtained from three streams which would scarcely attain the dignity of rivers in this country. But all the water for London not drawn from the deep wells in the Kent chalk is carefully filtered under government supervision, and at low rates per square foot of filter area. The London filters are usually worked at rates of 37 to 40 galls. per square foot of filter area per day, less than one-twelfth of the rate for which the Tacoma filter was planned, and one-twenty-fifth of the rate at which the paper states it was occasionally worked.

High speed in any filter can be obtained by the use of thin beds of coarse sand, but high efficiency is more to be sought than high speed,

Mr. Hill. and, judging from the present information upon the subject, this is to be had only with thick beds of fine sand operated under low heads and at low rates per square foot of filter area. A test of a filter should show the changes effected in the quantity and character of the suspended and dissolved organic matter, and in the bacterial condition of the water, and especially the influence of the filtered water on the typhoid fever death rate of the community supplied.

While the most satisfactory showing in the typhoid fever rates has been obtained from a city depending upon filtered water, The Hague, still among the principal cities of the world showing the highest death rates from typhoid fever are several using only filtered water; Dublin, for instance, with an average rate for the past five years of nearly 60, and Atlanta, with an average rate of 93, per 100 000 of population. As a rule, cities like Vienna, Munich, New York, Boston and Newark, which seek their water beyond the reach of serious pollution, show much better continuous and average rates of typhoid fever than the cities which depend upon previously polluted unfiltered or filtered water, which seems to indicate that safety in the matter of public water supplies is in the direction of sources of natural purity, rather than in attempts to purify a polluted water by filtration, at least by the high-speed filtration as described in the paper.

Mr. Hazen. Allen Hazen, Esq.—The question of water filtration is an important one in the United States where, as a matter of necessity, many cities take their water supplies from rivers and lakes which are muddy and which are polluted by sewage. Processes of filtration have been developed in densely populated European countries for purifying the water from such sources, which leave little to be desired in the results obtained. The cost of these processes, however, appears to be excessive to American communities which have obtained their water without other costs than that of pumping, and do not, as yet, realize the great value of a pure water supply.

As a result of this condition, there are numerous and determined efforts to devise and secure the adoption of other and more rapid processes of filtration by which water can be treated at less expense than by the comparatively slow and thorough processes commonly employed in Europe. The one all-important question to be raised in regard to all processes of this nature is whether or not they are capable of purifying the water in such a way as to make it suitable for the purposes for which it is intended.

The paper describes a filter which was constructed at a very small expense and which allowed a considerable quantity of water to pass through it. The author has unfortunately neglected to state what degree of purification was obtained, whether or not the water was rendered suitable for city supply, and whether or not the filter could be depended upon to remove the algæ or the bacteria and other organisms which were or might have been present in the unfiltered water. The

paper thus has only a suggestive value, and while ideas may be obtained from it which will be useful in designing other filters, it will not be safe in other cases to follow the construction described without investigating the results obtained by this apparatus, which are not given in the paper. Mr. Hazen.

In regard to the details of the paper, the rate of filtration is given in the somewhat unusual unit of gallons per square foot daily. It is greatly to be desired that some unit for rate of filtration should be adopted which is applicable to all the rates ranging from quantities used in sewage treatment by irrigation to the much higher quantities used in water filtration by European methods, and to the still very much higher rates employed in mechanical filters for treating water. At the present time the quantities are expressed, according to circumstances, in English or American gallons per square foot, per square yard or per acre, or in vertical inches or feet, and for time, intervals of minutes, hours or days, making a total of 24 possible combinations, the greater part of which have been used in some way or other in connection with filtration. There is probably no other unit so convenient as the metric one of a vertical column of water equivalent to 1 m. daily on the effective filter surface. But as it is impracticable for various reasons to use this unit in the United States at the present time, the unit of 1 000 000 galls. per acre daily, which is very nearly equal to the above-mentioned metric unit, has many advantages, notwithstanding the objection that may be raised to a unit of area as large as an acre for areas as small or smaller than that of the filter described in this article.

In regard to covering the filter which is spoken of as "an absolute necessity in this climate," that is, at Tacoma, the writer's information is, perhaps, less complete than could be desired on that climate, but from statistics at his disposal the winter temperatures of the Pacific coast are very much higher than those of the Atlantic coast points and correspond more nearly with those of western Europe. There open filters are successfully used in much higher latitudes than that of Tacoma, and it may be a question whether covering would be necessary or desirable in that place.

The sand used seems to have been rather coarse; it is stated that in order to allow the high velocity, 500 galls. per square foot per day or 21 780 000 galls. per acre daily, it was necessary to use "a sand of large grain, free from all finer matter, and there was the danger that the chief usefulness of a filter, viz., its ability to thoroughly strain out all impurities, might be lost." This is, indeed, a serious danger, for the efficiency of filters decreases rapidly with the size of the sand grains employed. To avoid this it is stated that a coagulant was used. The coagulant selected was metallic iron, over and through which the water was taken, but it is very doubtful whether the term coagulant should be extended to cover metallic iron used in this way. A coagu-

Mr. Hazen. lant in filtration is strictly a substance added to a water or liquid in solution, which, by chemical or other changes, becomes precipitated in the liquid and forms an insoluble substance which surrounds and combines with suspended or dissolved matters in solution, and allows the whole mass to be more readily removed than the matters could be removed by themselves. If water is agitated in contact with metallic iron, it will sometimes (depending upon the composition of the water and other circumstances) take a portion of the iron into solution as ferrous carbonate, and this may subsequently become oxidized and precipitated as ferric hydrate. In case enough iron is dissolved to form a substantial precipitate, and other conditions are present to make it do so, the iron may be regarded as a coagulant, but in the present instance there is no reason to think that any such quantity of iron went into solution or was precipitated; in fact, the faint milky tinge mentioned shows that this was not the case, and the iron employed was only useful in so far as it acted as a screen to remove insects and other floating matter in the water, as mentioned by the author; and as these would have been removed in any case by the sand, it is not apparent that the iron aided the process in any way.

Mr. Cummings. Robert A. Cummings, Assoc. M. Am. Soc. C. E.—Criticism of this paper is practically disarmed through the author's admission that it is not in strict accordance with the best ideas. Since he does not give the results of filtration by his new form of filter, it may be of doubtful efficiency. Indeed, it is not clear how such a filter bed can be efficient.

The author appears to have concluded that the action of sand filtration is purely mechanical. The successful filtration of water depends on the sound appreciation of this action. It is generally understood that there are two distinct actions in sand filtration, viz., the straining and the adhesive actions. On the one hand, water holding matter in suspension is strained as through a sieve; and, on the other hand, water is filtered through a sand filter as in passing through a settling basin. The action in the former case may be considered as a retaining one, and admits of a high velocity; and in the latter as an adhesive one, requiring a low velocity for the settlement of suspended matter. The attraction by and to the sand grains of particles so much smaller than the interstitial spaces substantiates the correctness of this last view. It is now well known that when the usual limit of rate of flow is exceeded, the efficiency of filtration is depreciated. All methods of simple sand filtration at extraordinary velocities of flow cannot be relied upon until it has been clearly shown that they are efficient. For the removal of bacteria, sand filtration undoubtedly depends upon the delicate deposit of organized matter which forms on the top of the sand. The efficiency will depend upon the quality of the water, the temperature, the ripeness of the sand, etc.

The advantage claimed for upward flow filtration is the high velocity

obtainable. This can be secured only at the expense of efficiency of filtration. It has been pointed out that with a high velocity the action is that of a mechanical strainer, which retains only the coarser particles, and has a very small bacterial efficiency. Does the film so necessary in sand filtration form at all in the upward flow filters? The writer thinks not. If it does, at what point? Suppose it forms in the sand at the top of the filter, for it will not form in the gravel; the whole filter bed becomes impregnated with organic matter and requires renewal at each clogging of the beds. The simple reversal of flow of filtered water will not cleanse the bed. The whole mass of sand must be cleaned and exposed to light and air. The waste of filtered water for this purpose is a serious objection, and the pollution of the streams below is not permissible. Mr. Cummings.

The writer was recently consulted with regard to much trouble with the upward flow filters at Wayne, Pa., which were found washing the sand, or rather agitating the sand, as noted by the author. The filters had a bed composed of crushed slag, gravel and sand. They are not in use now.

It has been found at the Berlin Water-Works that open filter-beds are more efficient than covered ones, and the late Mr. Gill, chief engineer, has stated that the choking of the pores of the filter and the growth of algæ at the surface of the sand are most valuable aids to the micro-biological improvement of the water.

It is agreeable to note that the result of the author's experience with iron as a purifier should be in accordance with results found elsewhere. It may be noticed, however, that Mr. William Anderson used spongy iron at the Antwerp Water-Works several years ago, and it purified the water satisfactorily, although the spongy iron soon became choked. After many experiments the latter was replaced by the agitation of metallic iron with the water, and by sand filter beds.

The apparatus for the Anderson process may be briefly described as consisting of a revolving purifier, a small engine for revolving the purifier and a tank fitted with a fine screen for separating coarse particles. The revolving purifier is a wrought-iron cylinder supported longitudinally on hollow trunnions fitted with stuffing-boxes through which the inlet and outlet pipes pass. The inside of the cylinder has curved ledges suitably arranged for scooping up the iron and showering it down through the water. Experience shows that the iron has very little tendency to move along the cylinder with the current; however, means are provided to check it. The screen is to intercept algæ and other large impurities, that may be in the water before it reaches the purifier, from the sand filter beds. The growth of algæ never takes place after the water has been purified.

The following explanation of the action that takes place with the agitation of metallic iron in water containing organic matter is given by Dr. E. Divers:

Mr. Cummings. "Water containing carbonic acid dissolves iron in the form of carbonate, at the same time liberating hydrogen when no deoxidizable matters are present. One effect, well known, of depriving water of its dissolved carbonic acid, is to precipitate any calcium, magnesium and iron carbonates which the carbonic acid may have been keeping in solution. In this way spongy iron will become coated over and cemented together into a hard mass by some calcareous waters. What iron carbonate is not thus precipitated becomes afterwards changed by atmospheric oxygen into ferric hydroxide and deposited as a rusty sediment. Oxygen, nitrite, nitrate and no doubt some other of the oxygenous matters in solution in the water are consumed, partly by contact with the metallic iron in presence of the carbonic acid and partly afterwards by the iron dissolved as carbonate.

"It is not easy to admit that the action of iron upon water holding carbonic acid in it can be effective in destroying or precipitating dissolved albuminoid matters from the water. Rather must it be considered that the purification of water from matters indefinitely classed as albuminoids consists in the removal of organisms living in the water. The activity of iron in depriving water of bacteria is just what might be expected, since a microbe in water holding carbonic acid gets into a field of powerful chemical action when it comes in contact with bright iron and will naturally be paralyzed, if not killed outright. Further, water, freed as it is by iron of both carbonic acid and oxygen, must be ill-fitted for bacterial life, while the dissolved ferrous carbonate will, even in the minute quantity of it present, be a powerfully poisonous agent, like all such reducing or deoxidizing agents.

"In accordance with this account of the probable mode of action of the iron in killing and removing bacteria is the fact that it is only quickly after contact of the water with the iron that bacteria are so strikingly diminished in number, for towards the de-aerated water the iron becomes passive as glass, and new generations of bacteria may knock up against it with impunity, if otherwise able to live in the water."

Having considered the *modus operandi* of the Anderson process, it will be readily appreciated that the author's method of using old horse shoes, etc., added little or no value toward purifying the water.

Dr. E. Frankland has recently stated that a filter ought to be cleaned as seldom as possible, owing to its inefficiency for some time after cleaning, and he recommends an increase of storage capacity, which would give the sand filter less work to do; but this would only lengthen the time for the ripening of the sand. In the Anderson process an inorganic film of ferric oxide is deposited on the surface of the sand from the time the filter is started to work, which appears to obviate this difficulty. The conversion of the protosalt of iron formed in the water during its passage through the revolving purifiers into insoluble ferric oxide results in a coagulated precipitate, in which bacteria are entangled and imprisoned, the coarse-grained deposit thus formed being readily arrested at the surface of the sand, into which it does not penetrate. About four hours is given for the formation of the film.

From the analysis by Dr. Van Ermengen of a series of samples

taken hourly from a sand filter outlet at the Antwerp Water-Works, on September 9th, 1893, the folowing results are given: Mr. Cummings.

Hours after starting filter.	Number of microbes per cubic centimeter.	Hours after starting filter.	Number of microbes per cubic centimeter.
4	30	11	30
5	30	12	20
6	27	15	50
7	320*	18	52
8	25	24	25
9	30	30	25
10	39		

In the report of Dr. Henry Leffman and Dr. William Beam on the results of a six-month trial at the Belmont Water-Works, Philadelphia, the above results are fully confirmed. Their report reads:

"They show that it acts to remove suspended matter of every character, and to diminish ammonium compounds, dissolved organic matter, whether nitrogenous or not, nitrites or nitrates. The reduction in the number of microbes is especially to be noted, not only so far as the actual figures are concerned, but in view of the fact that there is now no doubt that the dangerous effects of water are due to these agents."

In the annual report of Dr. P. Miquel, published in the *Annuaire de l'Observatoire de Montsouris* for 1894, he states that the average of 22 samples shows that the number of bacteria in the original water was reduced 99.57% after purification and filtration, five showing a percentage of improvement of 99.9 per cent. The average number of bacteria in the original Seine water during the period of the test was 396 000, and the average speed of filtration was 75 galls. per square foot per 24 hours.

A striking example of the difference in the efficiency of a sand filter in the chemical improvement of a river water when used with and without the Anderson process is furnished by the analyses by Dr. H. Swete. In a paper read before the Sanitary Congress at Portsmouth, England, September, 1892, he states:

"I have divided these analyses into three stages: *First.*—The period before the purifiers were set to work. *Second.*—The intermittent period, during which period the continual structural alterations were being made to the filters, causing disturbance to the sand, and the crust formed on the surface of the filters. *Third.*—The third period, when the works were completed and a fair average result of what the system will effect could be estimated. These periods show the following percentage improvements in three important points:"

* Probably due to an accident to the sample.

Mr. Cummings.

PERCENTAGE OF IMPROVEMENT.

DATES.	Free ammonia.	Albuminoid ammonia.	Oxygen to oxidize organic matter.
First period	45	30	35
Second period	77	60	64
Third period	100	70	66
River in flood	97.8	75	73.5

It is now generally admitted that ordinary sand filters require the greatest care to avoid sudden variations in the rate of filtration, which destroy their delicate film. The ferric oxide film is not nearly so delicate, and allows greater variations in the rate of filtration; hence a greater speed of filtration can be obtained with as satisfactory results as from the larger area required for ordinary sand filters.

In the spring of 1892, experiments were made at Hampton, near London, to determine whether the life of a sand filter, when used in conjunction with a revolving purifier, would be lengthened or shortened by the addition to the water of the iron oxide. Two small sand filters, each having an area of 36 sq. ft. of sand surface, were constructed side by side, the one receiving Thames water direct from the river, and the other the same water passed through a purifier delivering at the rate of 500 galls. per minute. Owing to the shallowness of the filter tanks it was only possible to maintain a depth of 1 ft. 6 ins. over the sand in the filters, a circumstance unfavorable to the Anderson process as the time for aeration and coagulation of the iron oxide was reduced to less than half the normal period allowed.

The results of the trials showed, however, that the filter receiving the water purified by iron delivered from 25 to 50% more in the same number of hours than the filter working under ordinary conditions, the greatest difference in favor of the purified water being when the river water was most turbid.

The writer is informed that the Compagnie Génèrale des Eaux and the Compagnie des Eaux de la Banlieue, supplying water to Paris, have recently installed large plants for the purification of the Seine water by the Anderson process.

In a paper on the "Revolving Purifier Process," read by Mr. William Anderson, at the meeting of the British Association at Cardiff, in 1891, the author states:

"With regard to the working expenses, accurate figures can be given of the cost of the process during the year 1889, at the Dordrecht Water-Works. The purifier at these works has a 14-in. pipe and can purify 1 250 000 galls. daily; it is automatic, being driven by a small water motor worked by the water which passes through the cylinder, a very economical arrangement.

"The figures for the year 1889, are as follows:

Mr. Cummings.

Iron consumed per 1 000 000 galls. treated ...	13½ lbs.
Speed of filtration per square foot per 24 hours	100 galls.
Total quantity of water treated during year...	194 000 000 "
Total cost for the year, including iron filter cleaning, maintenance and repairs.........	$267.50
Average cost per 1 000 000 galls. purified ...	1.37

"The iron used is in the form of punchings, ⅜ in. to ⅞ in. diameter, costing $11 50 per ton."

More recent figures from the small plant at Boulogne-sur-Seine give an average cost of 0.0016 franc per cubic meter, or about ⅐ cent per 1 000 galls. ($1.43 per 1 000 000 galls. for a small plant of 1 100 000 galls. per day).

Mr. Hawks.

A. McL. Hawks, Jun. Am. Soc. C. E.—It must be borne in mind that the plant described in the paper was constructed in great haste and for a very small sum to remove some specific causes of complaint from the water then being supplied to the city of Tacoma. The work could not be delayed long enough to send samples of the water to a biologist and carry on correspondence sufficient to determine the exact causes and best means of obtaining entire relief from all sorts of impurities. It was a case which demanded immediate action. That no analyses could be given is a matter of regret to the author ; samples for this purpose were taken and were furnished to the company, but no results were ever given, if analyses were made. The actual result of the operation of this plant was the removal of the causes so that no further complaints were made.

Moreover, the work was commercially successful, which is the final test of all engineering work, for though engineers may plan ever so skilfully and scientifically, if they do not gain the approval of the ordinary business man their work is of little account. The plan of the Tacoma filters was laid before the Water Commissioners of the city of Wilmington, Del., who were then considering filtration of the water supplied to that city. Two of the members made a trip to Tacoma for the purpose of investigating this plant, and spent several days on their mission. They visited the filters with the author, and had them blown off and refilled and blown off a second time. Even though the beds had been indifferently cared for during nearly five months after the author had turned them over to the operating department, the visitors were highly pleased with the working of the plant. They afterwards visited the officers of the water company and made private inquiries for the purpose of determining the improvement in the character of the water after the filters were put in service. So well were the commissioners satisfied with the result of all their inquiries, that they returned to Wilmington and authorized the construction of a large plant for their city, introducing all the essential features of the author's plant and the additions which had been advocated by him but elided in the effort for greater economy of con-

Mr. Hawks. struction and operation. The Wilmington plant has been constructed about two years, and should be able to furnish many items of interest and give the very data which are missing from the paper. It was hoped that such items and data would be drawn out in discussion.

No one in these days thinks "the action of sand filtration is purely mechanical." It is distinctly stated that the delicate deposit mentioned by Mr. Cummings was formed at the bottom of the sand layer in the glass-sided upward filter at St. Louis.

The samples of water taken from the blow-off of the Tacoma plant when the filters were reversed showed a large amount of filth was being removed from the water and carried entirely without the beds; if a small amount was caught and held by the gravel, it would only serve to form the film upon the surface of the sand so necessary for the best results. So long as the sand is not permitted to boil, so long as it is perfectly quiescent, this film does not penetrate the surface any appreciable distance. The amount of filtered water wasted in reversal is 0.5% of the filter's daily capacity. Air is thoroughly drawn into the beds by the suction of the water subsiding at the time of reversal. There can be no reason for letting light and air in upon the top of these filters; the water standing there has already been purified. It would be like purifying water in an ordinary filter, and then exposing the clear-water basin to fresh contamination.

The iron filings, turnings, punchings, etc., began to clog within three days after they were placed in the flume; the smaller particles adhered to the larger ones in the first week, and in two weeks there were large coherent masses of rusted iron in the flume. Is it not possible that what has hitherto been unexplained, viz., the myriads of minute insects collected on the iron in the flume may be due to some such action as that described by Dr. E. Divers in the correspondence by Mr. Cummings? While they were in the water no movement could be seen, but after they had been exposed to the air for a few minutes, say from five to ten, they would begin to move, and, as the water evaporated, would become very lively. Why is "bright iron" specified? If the iron was removed and subjected to fire frequently enough to permit it to give off the protosalt when again immersed, is not that sufficient?

It is said with regard to the Dordrecht Water-Works: "The purifier * * * can purify 1 250 000 galls. daily," while a little farther on it is stated with regard to the operations during 1889: "Total quantity of water treated during the year, 194 000 000 galls." This may mean either that the purifier ran half the time or that it ran at half the "speed of filtration per square foot per 24 hours, 100 galls." If the sum of $15.06, the cost of the iron for 194 000 000 galls., be deducted from $267.50, the total cost for the year, it leaves $252.44 for filter cleaning, maintenance and repairs. As the apparatus is said to operate automatically, no part of this sum can be for operation.

The filter was run by the author but a few weeks. It was operated some months after that by the company, but without any records being kept. It is true the St. Louis upward filter clogged steadily, though reversed frequently, and needed greater starting head after each reversal; but this filter only permitted the water to be drawn off comparatively slowly. Once, through accident, it was very suddenly emptied, with the result that it did not require any greatly increased head to start it again. Mr. Hawks.

The coagulant in the Tacoma plant did not have the effect of binding the grains of sand together. For the purpose of determining that fact, and also as to the penetration of foul matter into the bed as well as could be detected by the eye (the greater part of the filth had a distinctly visible light brown color), a small pit was dug in the middle of one of the compartments after the plant had been running about a month. The sand was perfectly free from any such binding, and appeared to be perfectly clean to the surface of the gravel beneath. It was intended to keep an account of the iron consumed, but the time during which records were kept was not sufficiently long to show any appreciable loss upon so great an amount as 8 500 lbs. At the rate given for the Anderson process in the Dordrecht works, the loss for a month in this plant would not have been 10 per cent. It was intended to weigh the iron every three months to determine the loss, but this was never done.

The author agrees with Mr. Hazen that some unit for rate of filtration should be adopted; but why not that of gallons per square foot? It is much easier to use than millions per acre, and that it is not unusual is shown by three of the discussers of the paper adopting that unit, and one using it in connection with the 1 000 000 galls. per acre unit.